1 March 2010

Dr. Thomas Swean, Jr.
Office of Naval Research
Office of Naval Research
ONR Code 321
875 North Randolph Street
Arlington, VA 22203-1995

Subject: Annual Report

Reference: Contract N00014-09-C-0301
(SRI Project P18858)

Dear Dr. Swean:

SRI International is pleased to submit our Annual Report entitled "AUV-12 Sonar Integration and Evaluation." This report has been prepared in accordance with the requirements of CDRL A001 of the referenced contract.

Technical questions concerning this report should be addressed to John Kloske at (727) 498-6735; all other matters should be addressed to me at (650) 859-4424.

Sincerely,

Margaret Baxter-Pearson

Margaret Baxter-Pearson
Division Manager of Contracts

Enclosure

Cc: DCMA Northern California – Letter Only

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AUV-12 SONAR INTEGRATION AND EVALUATION

ESD-18858-AR-10-075
SRI Project Number P18858

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Attention: Dr. Tom Swean

Contract Number N00014-09-C-0301
CDRL A001

Approved:

Lawrence Langebrake, Director Marine Technology
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1 INTRODUCTION

The primary goal of Contract N00014-09-C-0301 is to integrate the CodaOctopus EchoScope MKII (ES MKII) high-resolution, volumetric three-dimensional (3D) sonar system (Figure 1) into a Bluefin Robotics B12 autonomous underwater vehicle (AUV) payload. Previously, SRI International (SRI) built and tested an AUV payload consisting of the BlueView Technologies 3DSLS (Figure 2), a multibeam sonar that, when fused with the navigation data, can generate highly detailed 3D mosaics. As part of the current effort, we will compare performance of the ES MKII and 3DSLS sonar payloads.

Both the ES MKII and the BlueView 3DSLS produce 3D data, but in different ways. An initial comparative analysis will enable assessment of capability versus value for each system.

The primary objectives of this effort are as follows:

- Characterize the AUV navigation system and the BlueView 3DSLS, which has been upgraded with reduced side lobe arrays. The characterization tests will be performed over a debris field, as explained in Section 3.
- Integrate the ES MKII into a Bluefin B12 12.75" diameter AUV payload.
- Extensively field-test and characterize both 3D sonar systems with the AUV.
  - The AUV was built specifically for the purpose of scanning ship hulls, so the comparative analysis will be of the two sonar payloads scanning a ship hull.

The initial application of this technology is envisioned to enhance port security and the security of our military assets at home and abroad.

Figure 1. CodaOctopus ES MKII 3D volumetric sonar (approximately 12.75" W x 16" H x 4.5" D and weighing approximately 44 lb in air).

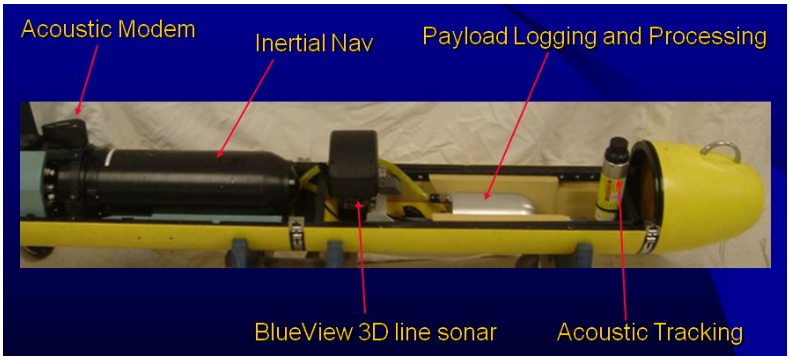

Figure 2. The MIP BlueView MB1350 sonar payload. The main components include the acoustic modem and AUV inertial navigation system as part of the AUV tail section; the MB1350, payload data logging and processing module, and acoustic tracking transponder located in the payload section.

2 APPROACH

The initial step for this project was to mechanically and electrically integrate the ES MKII into a 12.75" diameter payload section. The ES MKII is large relative to the payload dimensions, and requires considerable power relative to what the AUV can deliver. The first step in the integration process was to verify that we could float the AUV level and trim with the sonar onboard, and to confirm that the AUV could deliver the power required by the ES MKII.

We verified the AUV power constraints with Bluefin Technologies, and found that dedicating the second payload connection on the AUV main electronics housing would provide just enough power to run the ES MKII. We used the other payload connection to power the payload data logging and processing pressure vessel. We also rearranged the logging and processing can with another payload-style connector, and rewired the internals to accommodate the data lines.

To physically install the ES MKII, we used our in-house ability to fabricate an AUV payload shell to accommodate the ES MKII’s size. This was accomplished by cutting rectangular slots and positioning the sonar on the bottom of the sub looking up—maintaining good center-of-buoyancy to center-of-gravity separation, and allowing the sonar to be positioned to scan ship hulls. We were also able to insert just enough foam to offset the 26 lb in-water weight of the ES MK II, along with the payload data can and the independent tracking beacon.

3 WORK COMPLETED

AUV Characterization Using the Upgraded BlueView 3DSLS

1. Tested and evaluated the B12 inertial navigation system (INS) with and without the aid of the topside ultra-short baseline (USBL) tracking system.
   - This was accomplished by conducting a series of surveys of a construction debris field within Tampa Bay, Florida. The asymmetric distribution of the bottom debris allowed the AUV navigation error to be estimated by the degree of alignment correction needed to eliminate discontinuities among the objects (Figure 3).
2. Ran at least three, seven-hour missions over different terrains and objects (mines, improvised explosive devices, etc.) surveying an area of 500 m × 500 m using the 3DSLS upgrade with reduced side lobe arrays. Throughout the mission, during these surveys real-time USBL positions were sent to the AUV INS using a WHOI micro-modem. These runs were to validate the performance of the upgraded 3DSLS.
   - Figure 4 shows the results of a smaller targeted survey (100 m × 50 m) over test targets. The results of this test and others confirmed that the INS drift rate is on the order of 0.25% of the distance traveled; these results were very reproducible.
3. Created GSF (generic sensor *format)* files from the 3DSLS data to reduce file storage requirements, minimize data processing, and provide NAVO compatibility.

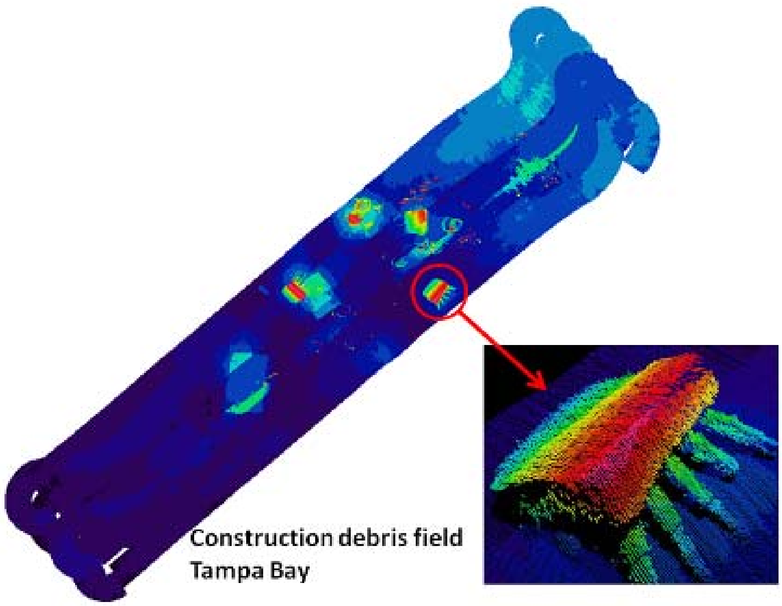

Figure 3. Example AUV survey using the BlueView 3DSLS (1.35 MHz) multibeam sonar. The survey area is of a construction debris field within Tampa Bay. The asymmetric scattering of the debris allows the navigation error in the AUV system to be estimated based on the degree of alignment correction needed to remove discontinuity among the objects.

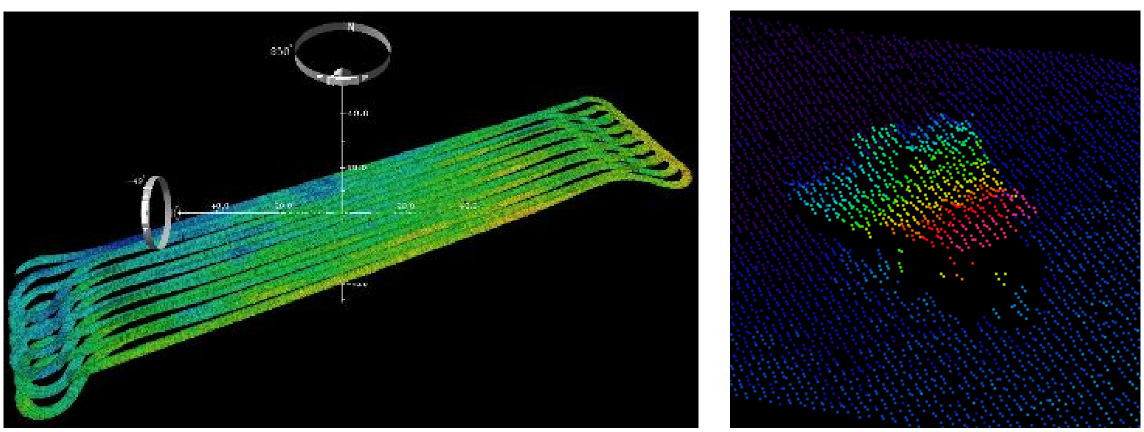

Figure 4. Results from a targeted AUV survey using the BlueView 3DSLS (1.35 MHz) over a mine and minelike objects. The survey width is 50 m, while the survey region of interest is 100 m. The 3D geo-referenced data products (left) clearly show the stabilization portions of the individual tracks (30 m on each end) and the high precision of the AUV navigation system. The image at right is of a deployed test target.

The ES MKII payload was built to support both ship hull scanning and standard bottom surveys (Figure 5). During the previous remotely operated vehicle (ROV) testing phase, the AUV's ABS plastic hull material was determined by CodaOctopus to be transparent at the ES MKII operating frequency of 375 kHz (Table 1). This test was conducted by placing a small section of the AUV's ABS hull section (fairing) over the ES MKII projector and transmitter mounted onboard the ROV to evaluate any signal loss/absorption. No noticeable difference in the image data was recorded and follow-on analysis indicates that no major influence from the fairing was observed.

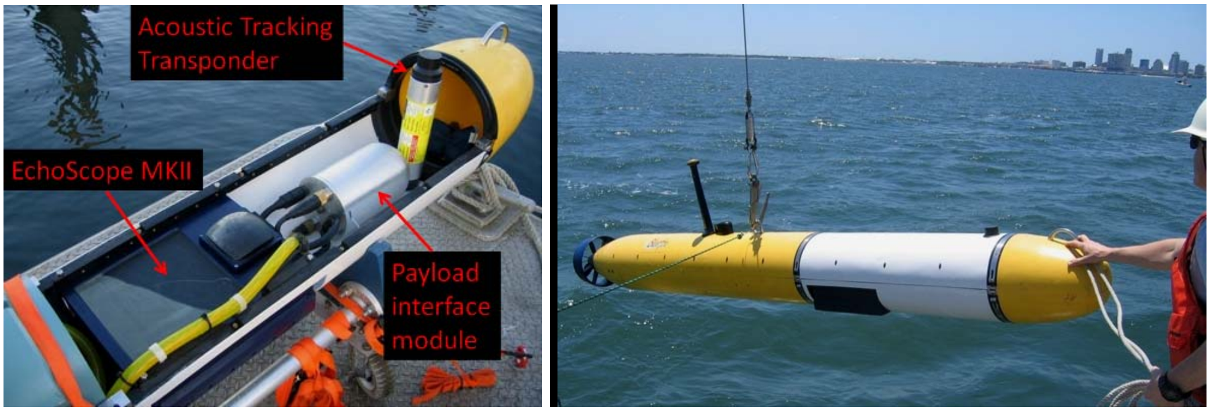

Figure 5. Left: Integration of the ES MKII sonar into a Bluefin B12 payload without the syntactic foam sections. The main components consist of the sonar mounted near the vehicle's center of gravity, the payload data processing module, and the acoustic tracking transponder. **Right: Deployment of the B12 AUV outfitted with the ES MKII payload in Tampa Bay during the ship hull scanning trials.**

Table 1. Statistical Analysis Conducted on Results from Tests Performed with and without AUV's ABS Hull Fairing

Test Case	Mean	Std. Dev.	1-Sigma Interval*
With fairing	77.7 dB	1.8 dB	75.9 to 79.5 dB
Without fairing	75.8 dB	2.3 dB	73.5 to 78.1 dB

* The 1-sigma intervals are overlapping → no difference introduced by the fairing.

The ES MKII power requirements (8 amps at 24 VDC nominally) required a dedicated DC-DC voltage regulator to be used in the payload, and necessitated a detailed analysis of the AUV power-providing capacity to ensure the B12 tail section would not be damaged. The B12 tail section can only provide up to 8 amps from its non-fused payload connections. The maximum current carrying capacity of 8 amps is limited by the gauge of wire used within the B12 payload interface. Therefore, we employed both payload connectors: one for the payload interface module and one for the ES MKII.

The software interface consisted of the CodaOctopus ES MKII digital interface unit (DIU) software module on our single board computer (SBC), along with our Bluefin interface software module. The DIU translates the user network user datagram protocol (UDP) commands into ES MKII sonar head control commands. The DIU also allows real-time navigation data to be associated to each sonar ping. A CodaOctopus recorder and ActiveX control allow the real-time ES MKII data (with embedded navigation data) to be logged to the SBC disk in the ES MKII native XTF format. We embedded the AUV real-time navigation data into the XTF files through the DIU software module using custom UDP messages.

The ES MKII was mounted near the AUV center of gravity, and custom syntactic foam was cut and mounted forward of the ES MKII to provide a slightly positively buoyant payload section that allowed for a trim (level) assembled AUV.

After fabrication, integration, and bench testing was complete, the AUV/ES MKII payload was run locally in Tampa Bay using the B12 AUV tail section (Figure 5). The testing was focused on ship hull scanning, specifically, scanning of the AUV support vessel, R/V *G.K. Gilbert*. These tests allowed direct comparison of the ES MKII and 3DSLS results. The process used to conduct the ship hull scans was as follows:

1. Launch the AUV near the target vessel with a “Hull Relative Survey,” a behavior pattern that is part of Bluefin’s Dashboard software.
2. Start the AUV mission using the radio frequency communication link. Once the AUV is submerged, begin transmission to the AUV via the acoustic micro-modem message type 28 that contains the target vessel position, true heading, course over ground, and speed over ground.
3. The AUV controller then uses the target position data as sent via the acoustic modem, including the heading and drift, to predict the future location and heading of the target vessel. The AUV aligns itself to scan the target vessel at a constant depth parallel to the vessel’s centerline (Figure 6). After each pass, the AUV controller calculates the next scan transect required to step over a predetermined distance (half the sonar swath width), to ensure complete hull coverage.
4. After the AUV dive, sonar data from each scan is post-processed to generate a 3D model of the ship hull (Figure 7).
5. Using the ship and AUV navigation data, the software translates each individual scan into a single model. Then the model is fine-tuned and completed using 3D alignment process. The final ship model is color-coded as a function of draft, where the deeper blues represent the deeper drafts (depths) and the lighter reds/oranges represent areas closer to the surface (Figures 8, 9, and 10).

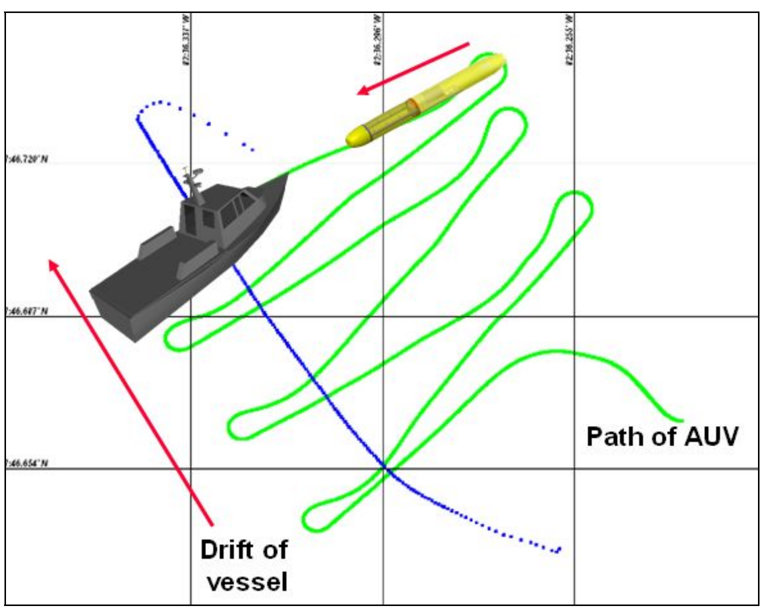

Figure 6. The ship hull scanning setup: the AUV scans the drifting target vessel.

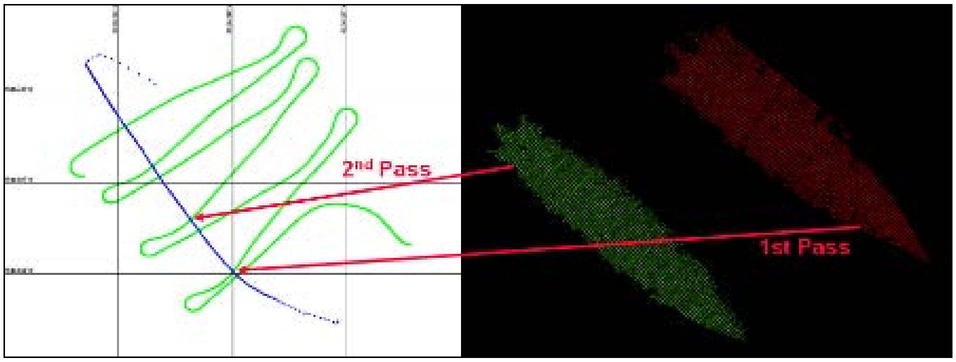

Figure 7. Individual scans of the target vessel from each pass.

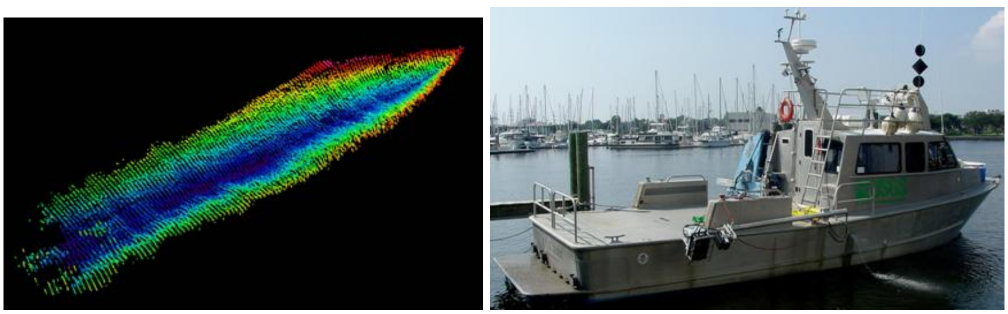

Figure 8. Left: Ship hull scan of the 50-foot long research vessel R/V *Gilbert*. The data were collected in Tampa Bay using the AUV 3DSLS payload (Figure 2). Right: Photo of the R/V *Gilbert*.

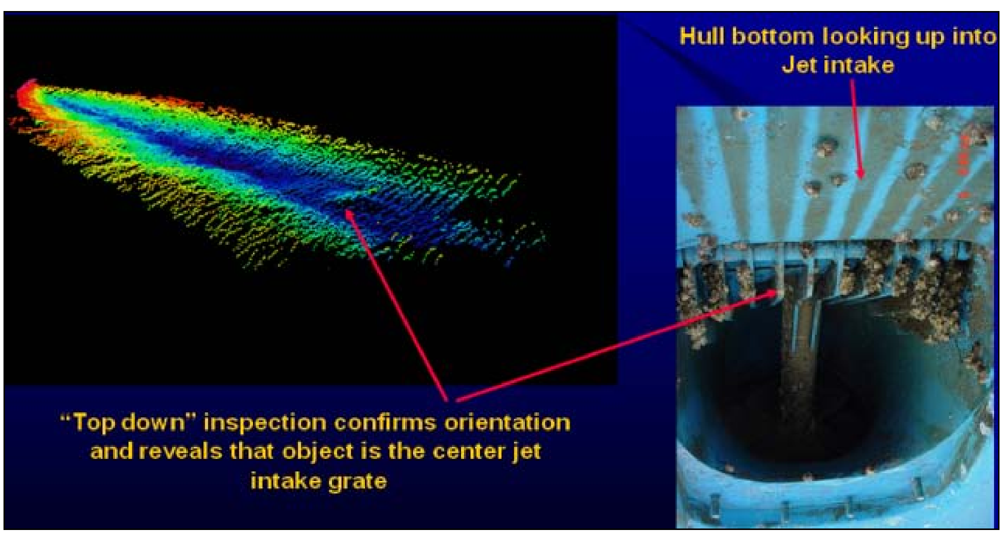

Figure 9. Detailed inspection of the target vessel model reveals an intake plate for the center water jet.

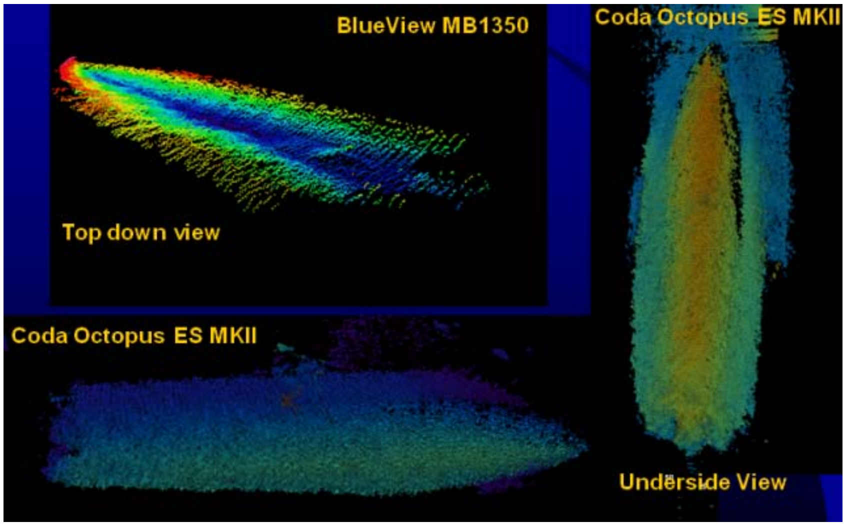

Figure 10. Initial data products from the BlueView 3DSLS (MB1350) and CodaOctopus ES MKII scans of R/V *Gilbert*.

4 RESULTS

The testing was conducted on different days under varying environmental conditions and at different AUV survey speeds (3 to 5 knots). The initial results of the ES MKII ship hull scans of the shallow draft (30 inches), triple-jet drive, RV *Gilbert* can be seen in Figure 10. Both the initial BlueView 3DSLS multibeam ("line sonar") and the CodaOctopus ES MKII 3D volumetric sonar units produced quality data that were quickly converted into 3D models of the ship's hull. The fact that objects as small as 1 foot in size can be clearly seen in models from data collected while the AUV scanned the target vessel at 5 knots is very encouraging for detecting small threat size objects (limpet mines, etc.).

Visually, the data products from the 3DSLS and the ES MKII are similar. The major differences between the two systems are in their physical size, cost, power consumption (and heat), stand-off distance, and the method of ensonification. The 3DSLS is significantly smaller, about one-third the price, and uses significantly less power than the ES MKII. (The 3DSLS-equipped AUV has approximately twice the run time of the ES MKII-equipped AUV.) Furthermore, the 3DSLS does not exhibit heat dissipation issues, and may have slightly better resolution than the ES MKII. However, the 3DSLS stand-off distance is one-fifth of what the ES MKII can do (keeping in mind that the further the stand-off distance, the less the resolution), and it is not a volumetric sonar, as is the ES MKII.

5 IMPACT AND APPLICATIONS

Future funding to refine the AUV ship hull scanning procedures to more closely match US Navy and US Coast Guard concept of operations would be the next logical step. Thereafter, the 3D sonar AUV payload capabilities should be migrated into smaller, two-person deployable AUVs, such as the REMUS and Bluefin 9" diameter vehicles. This would provide Navy and Coast Guard field personnel the capability to quickly scan ship hulls offshore from a minimally sized support vessel that could be readily deployed worldwide. Finally, the development of automated detection/classification tools would greatly enhance system performance.

6 FINANCIAL

The financial data provided are from the project execution date of 01/29/09 through 01/30/10. Base effort supported under ACRN AA ($220,000) reached 75% expended and notice was communicated on 07/01/09 requesting additional funding to continue. Funding was authorized under ACRN AB ($211,858) on 11/23/09 adding the balance of funding from CLIN 1 and executing and fully funding the Option and contract. No significant work was done between 1 September and 31 December 31 2009.

Current end dates for CLIN 1 and CLIN 2 are shown in the table below. A request to extend CLIN 1 end date to 07/22/10 at no additional cost to the government was requested by SRI on 01/20/10. As of the date of this report, no extension has been granted.

	Expenditures				Authorized			
Title	**Labor**	**ODC**	**Com-mitted**	**Total**	**Funding**	**Balance**	**Start**	**End**
AUV Sonar - CLIN-1	$214,144	$36,520	$0	$250,664	$357,473	$106,809	01/29/09	01/29/10
AUV Sonar - CLIN-2	$869	$0	$0	$869	$74,385	$73,516	11/23/09	07/22/10
Total	**$215,012**	**$36,520**	**$0**	**$251,533**	**$431,858**	**$180,325**	01/29/09	07/22/10

	CLIN 1	CLIN 2	Total	Expended
ACRN AA	$220,000		$220,000	100%
ACRN AB	$137,473	$74,385	$211,858	15%
Total	$357,473	$74,385	$431,858	58%

Previous Related Projects

ONR Award N0014-07-C-0722: Testing and Evaluation of the Mobile Inspection Package

ACKNOWLEDGMENTS

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